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Procedia Computer Science 40 (2014) 66 – 73

Procedia Computer Science

Fourth International Conference on Selected Topics in Mobile & Wireless Networking (MoWNet'2014)

QoS-aware Node Selection Algorithm for Routing Protocols in VANETs

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Abstract

In this paper, we present a QoS-Aware node Selection Algorithm (QASA) for routing protocols to be suitable for a particular class of opportunistic networks, when applied to the Vehicular Ad hoc Networks. Our algorithm aims to select the next-hop vehicle to communicate with, by exploiting the "bridging approach" for message forwarding *i.e.*, vehicles on the east (west) select from west (east). The QoS metrics that are being optimized are the throughput in the network, and packets end-to-end delay. In order to provide the best network performance, the algorithm utilizes a probabilistic rebroadcasting scheme based on different network parameters including vehicle density, inter-vehicle distance, and the transmission range for the vehicles. Moreover, QASA utilizes a transmission range-based metric that can be changed as per application requirements, whether it is high throughput or minimum end-to-end delay. Simulation results show the effectiveness of our approach in terms of improved QoS metrics in different vehicular network scenarios.

Peer-review under responsibility of organizing committee of Fourth International Conference on Selected Topics in Mobile & Wireless Networking (MoWNet'2014)

Keywords: VANETs, Reliability, Probability-based routing, Quality-of-Service

1. Introduction

Opportunistic networking techniques[1] allow mobile devices to exchange messages by having knowledge of the mobility patterns, and accordingly exploit the *store-carry-and-forward* approach. Following this technique, a message can be stored in a node and then forwarded to an available wireless link, as soon as a connection opportunity becomes feasible with a neighboring device, and such opportunistic next-hop forwards information towards a desired destination.

Vehicular Ad hoc NETworks (VANETs) are a special kind of Mobile Ad hoc NETworks (MANETs) in which packets are exchanged between mobile devices (vehicles) traveling on constrained paths, in case of Vehicle-to-Vehicle

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Peer-review under responsibility of organizing committee of Fourth International Conference on Selected Topics in Mobile & Wireless Networking (MoWNet'2014)
doi:10.1016/j.procs.2014.10.032

(V2V) communications, and between vehicles and road-side access points, *i.e.* Road-Side Units (RSUs), in case of Vehicle-to-Infrastructure (V2I) communications.

Opportunistic forwarding is the main technique adopted in Delay Tolerant Networks, and has also been extended in VANETs to achieve connectivity between vehicles via V2V so as to disseminate traffic information[2,3]. In particular, Agarwal and Little in[3] assume a bidirectional road, where vehicles' clusters formed in one direction of the highway come in intermittent contact with other clusters traveling in the opposite direction. Such contacts can be opportunistically exploited as a *bridging* technique, linking the partitioning that exists between clusters traveling in the same direction of the roadway. As a result, the connectivity can be maintained along the road. On the other hand, exploitation of RSUs together with inter-vehicle communications represents a viable solution to extend connectivity support in those scenarios where vehicles are not able to directly communicate each others. Such a combination is commonly referred to as V2X[4,5].

Based on the concept of *bridging* in a VANET, an open issue is the fact that any vehicle traveling along one direction (*e.g.*, east) can select any of the multiple vehicles on the opposite side (*e.g.*, west) of the roadway. How to choose a next-hop forwarder is a real challenge, as an optimum choice should consider numerous factors such as the longest inter-vehicle distance, link connectivity time, mobility pattern, and so on.

This paper addresses the best way to select the next-hop forwarder node, assuming the use of bridging approach not only when (*i*) there is no connectivity link along one direction, but also when (*ii*) the network performance (*i.e.*, link connectivity time, and throughput) ought to be improved. Based on the Quality-of-Service (QoS) requirement of a given application, we propose a routing protocol, namely QoS-Aware Node Selection Algorithm (QASA), which relies on choosing an opportunistic node for next-hop forwarder.

This paper is organized as follows. In Section 2, we provide a background on existing routing protocols for vehicular networks that exploit opportunistic networking. In Section 3 we introduce the proposed QASA protocol, by describing the main aspects through the analytical model, and the algorithm. The effectiveness of QASA is illustrated via simulation results in Section 4. Finally, conclusions are drawn at the end of this paper.

2. Related Work

For the past few years, routing protocols for vehicular networks have been a topic of interest in the literature. Different categories exist, such as the class of probability-based routing protocols, which rely on the algorithm that allows selection of specific vehicles to communicate with, amongst many vehicles within the communication range of the source vehicle. As the main advantage, the use of probability in selecting a routing protocol is based on avoiding the flooding of the network with duplicates of the same packet. Clearly, this provides a significant improvement in the performance of the network, since it reduces the number of collisions, and hence improves the throughput, as well as reduces end-to-end delay.

Among many works dealing with probabilistic routing protocols, we recall the ticket-based techniques[6], where the vehicle is selected based on stability, delay and cost metrics. In[7] Bae and Olariu assume that, before retransmitting, each vehicle determines a rebroadcast degree from fuzzy logic rules. The rebroadcast degree depends on the current traffic density of road, and the distance between previous-hop vehicle and current receiving vehicle. In[8], rebroadcast probability is a function of inter-vehicle distance, signal strength and the statistical distribution of the vehicles.

In[9,10], the CAREFOR technique considers the vehicle selection based on the probability that at least two vehicles will be qualified as the next-hop forwarders. Basically, CAREFOR considers not only the rebroadcast probability for one next-hop, but extends this probability up to two next-hops. This approach represents a two-hops prediction in selecting qualified vehicle as an effective next-hop forwarder. Finally, another work[11] considers a probabilistic relay aiming to provide a reinforcement node to relay the data packet instead of waiting for retransmission.

All these techniques are driven by reducing replica of a packet within the vehicular network. However, many applications have different QoS requirements, which routing protocol should also maximize[12].

In this paper, we consider a QoS-oriented and probability-based routing protocol for VANETs that maximizes the throughout while considering end-to-end delay. The routing protocol is developed by selecting a vehicle from opposite side of the highway *i.e.*, the east vehicle selects the vehicle on west side to communicate with, and vice-versa.

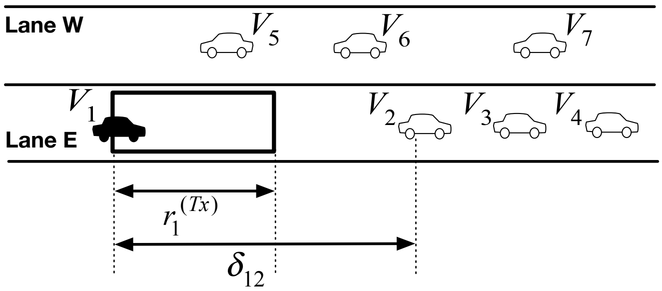

Fig. 1. Schematic of a vehicular network, with *bridging* approach. A source (*dark*) vehicle shall select a next-hop forwarder from the opposite lane, since the forward inter-vehicular gap is too large for allowing V2V links (*i.e.*, $r_i^{(Tx)} < \delta_{ij}$). The solid box represents the source's transmission range.

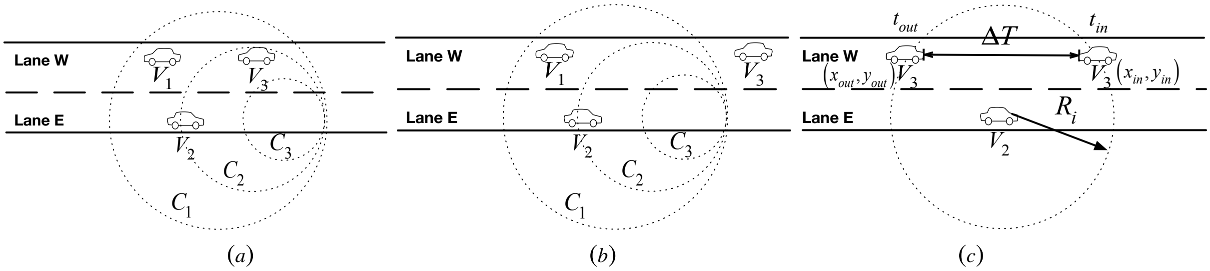

Fig. 2. QASA's main aspects. (*a*) Dividing the transmission range of a source vehicle (*i.e.*, the vehicle V_2) into smaller circular transmission domains (*i.e.*, with $C_1 > C_2 > C_3$) for next-hop selection. (*b*) The scenario explains the trade-off between time delay and throughput performance with QASA. (*c*) Coverage crossing time calculation, as a time interval that a vehicle experiences to cross a coverage area.

3. QoS-Aware Node Selection Algorithm

We refer to a vehicular network scenario comprised of two lanes (*i.e.*, lane E and W), where vehicles are being driven in opposite directions, as depicted in Fig. 1. Let us assume vehicles on lane E (W) are driving to the east (west) direction. We consider the vehicular network to have a highly dynamic topology, due to different mobility patterns that form vehicles' clusters (*e.g.*, vehicles traveling on the roadway are characterized by frequent link breakages that strongly hinder stable and durable V2V communications). It is worth mentioning that each side of road could consist of multiple lanes and our scheme is equally applicable as well.

In such a scenario, let us consider a source vehicle driving on the E lane. V2V communications along this lane cannot occur, since the inter-vehicular gap among the i-th source vehicle and its j-th neighbors (*i.e.*, δ_{ij} [m]) is so large that the source connectivity range (*i.e.*, $r_i^{(Tx)}$ [m]) results in a very short time as compared to this (*i.e.*, $r_i^{(Tx)} < \delta_{ij}$ [1]). Thus, the main aspect of QASA algorithm is to allow a source vehicle to be able to select the best candidate to be a receiver from the opposite lane (*i.e.*, the west side).

Consider Fig. 2 (*a*), when the vehicle on the east (*i.e.*, vehicle V_2) is getting ready to transmit a message to the west side of the highway, it will have two candidate vehicles as potential receivers on the west side within its transmission range (*i.e.*, vehicles V_1, and V_3). The best candidate would be able to offer the best QoS metrics in a VANET, specifically (*i*) the best throughput, and (*ii*) the least packet transmission delay. If the vehicle V_2 selects the vehicle V_1, the established connection will only last for a short time due to the vehicle V_1 moving out of the V_3 vehicle's transmission range. However, if the vehicle V_2 ends up selecting the vehicle V_3 instead, this will allow for the connection to remain established for a longer period of time due to the vehicle V_3 being in the source vehicle's transmission range for a longer period. The shorter the time the connection lasts, a larger number of connections can

[1]In Fig. 1, $i = 1$, and $j = 2$.

be established within the same duration. The disadvantage of establishing a new connection lies in the overhead of beaconing messages, and backoff algorithm.

3.1. Analytical Model

In order to analyze for selecting the best candidate vehicle, we divide the transmission range of the source vehicles into smaller circular domains [2], corresponding to actual transmission range (*i.e.*, the full transmission range, half the transmission range, and one quarter of the transmission range). These domains are the different ranges from which the source vehicle can select a next-hop forwarder vehicle. We investigate the performance of the VANET with regards to the different ranges for the vehicle selection.

Let us assume that R_1 is the radius for the circle C_1; R_2 for C_2; and R_3 for C_3. We develop an analytical model for the probability of the existence of a vehicle in each circular domain. The probability that a vehicle can be selected as a next-hop forwarder depends on two events, *i.e.*, (*i*) the vehicle is within the transmission range, and (*ii*) the vehicle is expected to a large enough connectivity interval to guarantee enough time for packet transmission and relay. Both conditions should be satisfied in order to select a vehicle as the best packet forwarder. We express the probability that a vehicle will be a next-hop forwarder (*i.e.*, p_{rx}) as follows:

$$p_{rx} = \Pr\left[d^* \leq R_i\right] \cup \Pr\left[\Delta T(R_i) > \tau\right], \tag{1}$$

where d^* [m] is the inter-vehicular distance from a potential forwarder to a source, $\Delta T(R_i)$ [s] is the expected time interval the next-hop vehicle is within the coverage area R_i (with $i = [1, 2, 3]$), and τ [s] is a given threshold to guarantee a larger connectivity time interval.

Let us consider Fig. 2. The probability that a vehicle is laying at distance $d = d^*$ from a source vehicle can be expressed as:

$$\Pr\left[d = d^*\right] = \frac{\lambda^{d^*} \cdot \exp(-\lambda)}{d^*!}, \tag{2}$$

where λ [veh/km] is the traffic density distribution on the highway, following a Poisson distribution.

From (1), the probability that a vehicle, laying at distance d^* from a source node, is inside the i-th coverage area C_i with radius R_i, becomes:

$$\Pr\left[d^* \leq R_i\right] = \frac{\Gamma\left(\lfloor d^* + 1\rfloor, \lambda\right)}{\lfloor d^*\rfloor!}, \tag{3}$$

where Γ is the incomplete Gamma function, and the operator $\lfloor\cdot\rfloor$ represents the floor function.

Again, from (1), the probability that a vehicle will experience a time interval ΔT [s], within a given coverage area, higher than a threshold τ [s] is as follows:

$$\Pr\left[\Delta T(R_i) > \tau\right] = 1 - \frac{\Gamma\left(\lfloor \tau + 1\rfloor, \lambda\right)}{\lfloor \tau\rfloor!}, \tag{4}$$

where ΔT [s] (also called *coverage crossing time*) can be expressed as the time difference between the entrance and exit instants of the coverage area (*i.e.*, t_{in} [s] and t_{out} [s], respectively), such as $\Delta T = t_{out} - t_{in}$, which becomes:

$$\Delta T = \frac{\Delta x}{||\mathbf{v}||} = \frac{2R_i}{||\mathbf{v}||} \cdot \cos\left[\arctan\left(\frac{y_{in} - y_{out}}{x_{in} - x_{out}}\right)\right], \tag{5}$$

with $||\mathbf{v}||$ [m/s] as the modulus of vehicle's speed vector $\mathbf{v}$, assumed to be constant for all the vehicles, and Δx [m] is the expected distance traveled by the vehicle within a given coverage area. Fig. 2 (*c*) depicts the schematic for ΔT calculation. Notice that the coordinates of vehicle's positions of the entrance *i.e.*, (x_{in}, y_{in}), and of the exit point *i.e.*, (x_{out}, y_{out}), of the transmission range, with respect to a coordinate system centered in the centre, are known, since we assume each vehicle is equipped with a GPS device. This computation is directly performed by each vehicle assuming a constant vehicle speed, and knowledge of the transmission range R_i.

[2] We assume each vehicle is equipped with an omnidirectional antenna.

3.2. QASA Algorithm

As it will be evident from the simulation results, limiting the selection range to the shortest range provides improved throughput, but it performs badly in terms of average time delay. Similarly, QASA assumes that the closer the vehicle is, the worse expected throughput will be, while it provides a reduced time delay. As an instance, we consider the scenario in Fig. 2 (*b*): if the vehicle V_2 on the east selects the furthest available vehicle in its transmission range on the west, QASA algorithm will select the vehicle V_1. This leads to small average time delay, but will result in a lower throughput. If the vehicle V_2 waits for a short expected time [3], it will be able to select the vehicle V_3, which will result in a higher throughput, but in a slightly higher time delay.

The choice between the vehicles V_1 and V_3 can be achieved by restricting the region from where the east vehicle selects a west vehicle. This restriction should be defined solely based on the type of application, since some vehicular network applications require minimum delay regardless of the throughput, while other applications require maximum throughput but are delay tolerant [1].

In order to overcome this trade-off, QASA algorithm needs to allow the vehicle to select the furthest possible vehicle available in a specific area within the transmission range, while considering QoS metrics *i.e.*, (*i*) the throughput of the network, and (*ii*) the average time delay for packet transmission.

Let us consider a source vehicle (namely, V_s) is driving alone on the lane E. QASA works through different phases as follows:

- **Phase** 1: The vehicle V_s on the east evaluates the current vehicular density within its transmission range (*i.e.*, C_1). Based on the vehicular density, it decides the appropriate radius of the circular region (*i.e.*, C_i with $i = 1, 2, 3$) in which the vehicles on the west lane can respond back to V_s;
- **Phase** 2: V_s broadcasts a Request-to-Broadcast (RTB) message to all vehicles in its transmission range. RTB includes the local vehicular density at the source node, the GPS location of V_s, and the radius computed from **Phase** 1;
- **Phase** 3: When all the vehicles in the transmission range of V_s receive the RTB message, they check if their location matches the requirements provided in the message. If they do not qualify, they drop the packet, otherwise they calculate the Reliable Forwarding (RF) probability, which is expressed as [9]:

$$p = \exp\left[-\frac{\rho \cdot (z-d)}{c} \cdot \frac{z}{z_i}\right], \tag{6}$$

  where ρ [veh/m] is the vehicular density, z and z_i [m] are the transmission ranges of V_s, and of the i-th neighboring vehicle, d [m] is the inter-vehicle distance between the potential forwarder and V_s, and $c \leq 1$ is a coefficient which can be selected to influence the rebroadcast probability (as a function of d).
  The decision of packet retransmission is taken by each vehicle by comparing the RF probability to a collision threshold (*i.e.*, Th_{coll}), as

$$Th_{coll} = 1 - \left[\exp\left(-\rho z_i\right)\right]. \tag{7}$$

  If the RF calculated value is larger than the threshold, then the vehicle broadcasts a Clear-to-Broadcast (CTB) message. Otherwise, the vehicle refrains from any rebroadcasting. The CTB message includes the GPS location of the vehicle;
- **Phase** 4: Once V_s receives the CTB messages, it determines which vehicle amongst those who responded is the furthest. Once that is decided, V_s transmits the packet with a destination address to the vehicle selected from the west area. All vehicles which receive the packet, but do not have their vehicle ID as the destination, simply drop the packet.

Applications in vehicular networks can have different QoS requirements. Some applications require minimum delay regardless of the throughput, while others require the opposite, and some applications may need a balance between throughput and average time delay. In order for the algorithm to be functional for different applications, we introduce a Full Range Portion (*FRP*) parameter that restricts the performance of the network as per the QoS

[3] It is evident that the vehicle V_3 will enter the coverage area C_1, in a short time.

Table 1. Simulation Parameters.

Simulation Parameters	Value
Simulation Runs	50
Simulation Duration	6000 s
Transmission Range	400 m
Vehicle Density	$[1, 65]$ veh/km
Vehicle Speed	20 m/s
Highway Length	3 km
Control Packet Size	2 KB
Message Size	32 KB
Message Generation Rate	20 packets/s
Bandwidth	10 MB/s

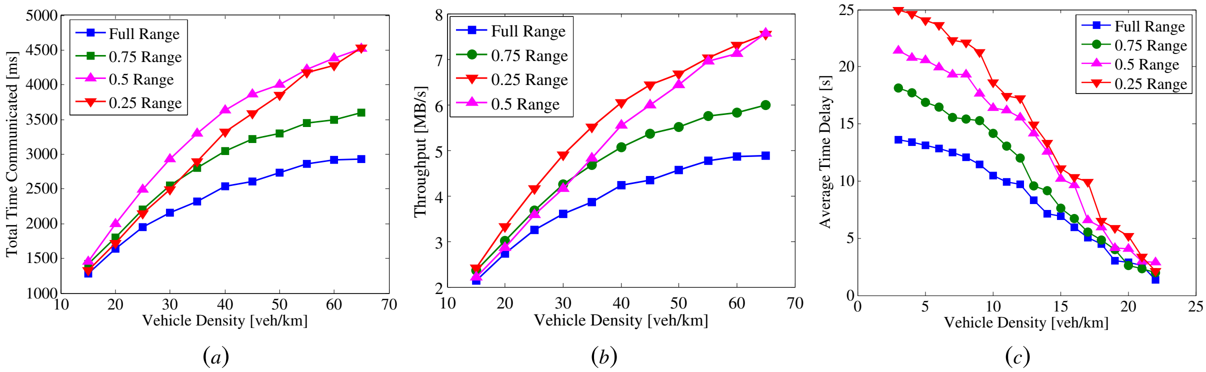

Fig. 3. QASA performance. (*a*) Total communication time, (*b*) throughput, and (*c*) average time delay, vs. the vehicular density for different transmission regions, with a packet regeneration every 20 seconds.

requirements. The *FRP* parameter represents the fraction of a full transmission range (*i.e.*, $0 < FRP \leq 1$), from which a vehicle on the west side can be selected by a vehicle from the east side. For example, in Fig. 2 (*a*), C_3 is selected using a *FRP* factor equal to 0.25; C_2 using *FRP* equal to 0.5; while *FRP* is equal to 1 for C_1. *FRP* is equal to 1 when the requirement is to provide the minimum average delay regardless of the throughput. The smaller the *FRP* is, better will be throughput the network experience, and the higher will be the average time delay. However, if the *FRP* parameter becomes too small, the region from which the west vehicle can be selected will be very restricted, and may cause failure in establishing any connection. Hence, *FRP* parameter depends mainly on the transmission range, and the vehicle density in the network.

4. Simulation Results

The metrics used in this simulations are the throughput, the total effective communication time, and the average time delay. The total effective communication time is measured after excluding any time used in setting up the connection or selecting the vehicles for communication. Table 1 collects main parameters used in the simulations.

The impact of the *bridging* approach on the vehicular network performance is assessed with the enhancement of the overall network connectivity. As expected, allowing bridging reduces the number of disconnected clusters, which will enhance the connectivity between vehicles on the network, allows for enhanced throughput, and reduces the average time delay experienced in the network.

In Fig. 3 (*a*), we present the total time communicated during the simulation runs, which proves the effectiveness of the concept of limiting the region within the transmission area of the east vehicle from which a vehicle on the west can communicate. As a result, QASA extends communication from the transmission area of the east (west) vehicle to a vehicle on the west (east). In Fig. 3 (*a*), we consider the case where any vehicle on the west within the source vehicle's transmission region can communicate with the east vehicle; this is demonstrated for full range of variations, and diameter of the region are changed from 0.75, 0.5, and 0.25 respectively. We observe that dynamically varying the transmission ranges in different regions can provide an enhancement of connectivity within the network. Note that different regions are located at the end of the transmission range. For example, in Fig. 2 (*a*), C_3 represents the 0.25 of full range C_1. Moreover, in Fig. 3 (*b*) we show the throughput analysis for the same regions. Again, high performance are obtained with a reduction of transmission ranges (*e.g.*, for 0.5 and 0.25 of full range we reach maximum values of throughput).

Notice that with the assumption of a continuously moving highway scenario, even at lower vehicle densities, each vehicle on the east will get the chance to communicate with each vehicle on the west, regardless of the communication range restriction. This is because QASA technique detects and selects a potential forwarder, based on both the transmission range, as well as the longest inter-vehicles distance (*i.e.*, the furthest vehicle in a coverage area). In the light of such discussions, it can be easily understood why at lower vehicular densities, the throughput is the same for different restrictions on the circular range.

In order to investigate the effectiveness of our algorithm, we also simulated time delay performance for a packet to be communicated from the beginning of the highway till the end (*i.e.*, end-to-end time delay).

We assumed vehicles generate message repeatedly during their trip through the highway. In Fig. 3 (*c*) we show the average time delay for the cases of the vehicles on the east lane that (*i*) are allowed to communicate with any vehicle within its communication range on the west lane (*i.e.*, full range), and (*ii*) are only allowed to communicate with vehicles on the west within a reduced circular area (*i.e.*, with diameter 0.75, 0.5 and 0.25 of the source communication range). As expected, the average time delay is low for the case of full range transmission, since the probability of having potential forwarders is higher than the cases of communication range restricted to 0.25, 0.5, and 0.75 of the transmission range. In case of shortest communication range (*i.e.*, 0.25 range) at low vehicle density, the average time delay is highest (*i.e.*, 25 s), since a source vehicle has to wait for other vehicles entering its transmission range.

Finally, we show that the use of *FRP* factor affects the QoS requirements for different applications in VANETs. Fig. 4 (*a*) presents the effect of the *FRP* factor on the total communication time in the network at different vehicle densities. As expected, smaller the value of *FRP*, and higher will be the vehicular density, more will be the communication time. Fig. 4 (*b*) depicts the same results for the total amount of bandwidth in the network. Maximum values are obtained for high vehicular density and low *FRP*.

5. Conclusions

In this paper, we have introduced QASA technique, which is primarily a forwarding node selection algorithm for routing protocols in opportunistic vehicular networks. QASA allows vehicles on one side of the highway to successfully select a vehicle from the opposite side that improves the QoS metrics for the network. The QoS metrics used to analyze the algorithm are total communication time, throughput, and packet end-to-end time delay.

We tested our system by extensive simulations and verified the effectiveness of bridging via QASA in vehicular networks. Results have shown significant improvement by QASA in terms of throughput, and end-to-end packet delay. Finally, we introduced the *FRP* parameter that provides better performance based on the QoS requirements for VANET applications.

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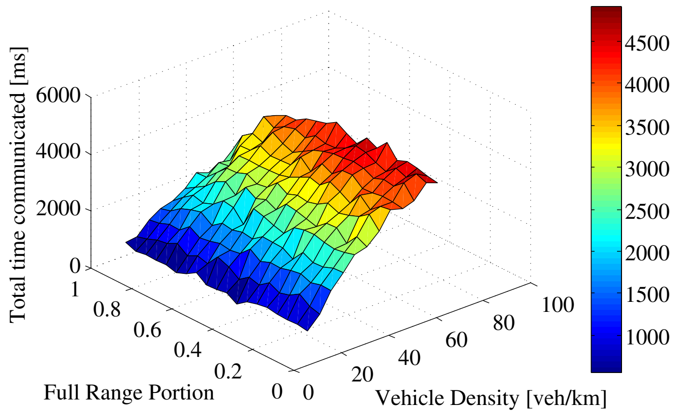

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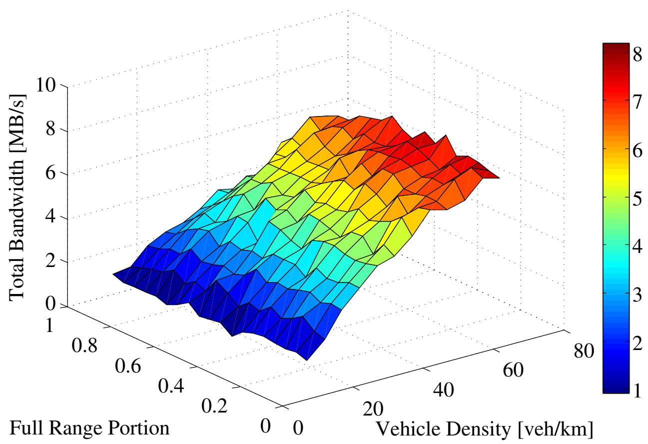

(*b*)

Fig. 4. Tri-dimensional graph of (*a*) total time communicated, and (*b*) total bandwidth, for different vehicular densities and *FRP* values.

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